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A Parallel Motion Creep Extensometer

by

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SUMMARY

The optical lever creep extensometer described in this Report was developed as part of a larger programme aimed at improving measurement and defining test conditions more precisely. The leaf spring parallel motion and the magnetic loading of the measuring roller are considered to offer significant advantages over conventional types. Their use in a creep research programme during a period of eighteen months is reviewed and suggestions for further improvements are made.

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* Replaces RAE Technical Report 70068 - ARC 32319.

CONTENTS

1 INTRODUCTION

The need for high-accuracy repeatable creep data has long been recognised both for research into the processes involved in creep deformation and for the provision of design data where a critical requirement is the extrapolation and interpolation of test results to service conditions.

The variation in the results of nominally identical creep tests carried out within and between laboratories[1] indicates that the above requirement is not being achieved. It is considered that differences in test conditions and variations in the accuracy of measurement are major factors and the Creep Laboratory of Structures Department has directed considerable effort over the last three years in an attempt to improve current techniques.

Among the many aspects involved it is suggested that the techniques employed in the following three areas are potentially the ones most capable of improvement.

(a) Temperature measurement and control.

(b) Axiality of loading.

(c) Strain measurement.

This selection does not imply that the attention to detail and the rigid control of the many other factors practised in testing laboratories is unnecessary and every attempt should be made to standardize all test conditions if the accuracy of test data is to be improved.

It is considered that satisfactory techniques have now been established in the three areas specified above and an adequate repeatability has been demonstrated for the current research programme now being undertaken[2].

Out of this work has come the sensitive, accurate optical lever extensometer which is the subject of this Report. Future Reports will discuss the techniques adopted to eliminate eccentricity of loading and the methods employed for more accurate temperature measurement.

2 EXTENSOMETER REQUIREMENTS

The general practice in creep strain measurement is to transmit the specimen strain to a point outside the hot area and measure it by the use of a suitable sensing element.

It is usual to use two extensometers attached to opposite sides of the specimen for several reasons. They supply two independent readings of strain for self checking and as some indication of load axiality. Alternatively the two extensometers can be integrated optically to give a larger multiplication factor. In addition two units form a symmetrical system, geometrically and thermally.

No departure from this practice is envisaged in the near future and therefore it is this general format which is the subject of this Report.

The perfect extensometer will never exist but in assessing how closely any design approaches the optimum the following requirements for a creep extensometer are put forward for consideration.

2.1 Attachment

Any factors influencing the specimens response to the test conditions should be minimised. The local stress concentration induced by the attachment and the moments and loads imposed by the extensometer are aspects for consideration.

The attachment should be made to the parallel portion of the test specimen for high accuracy work. it should be positive to avoid slip and the possibility of local creep at the attachment should be recognized.

2.2 Transmission

To avoid errors arising from elastic and creep deformations within the instrument the loads and moments imposed on the extensometer legs should be minimized and adequate stiffness provided.

The materials used should be selected for their dimensional stability and creep resistance at the operating temperature. Coefficients of expansion should be matched if it is not possible to standardize on one material throughout.

The strain at the specimen should be faithfully transmitted to the sensing element unaffected by any lateral displacements or rotations occurring during the loading and subsequent creep phases.

2.3 Sensing element

Specimen strain should be transferred to the sensing element without restraint, the element itself should not require resetting to cover the range of interest and a linear response over the range is desirable.

2.4 Miscellaneous

There should be no interactions with other parts of the test assembly or between the two extensometers themselves.

The strains indicated by the two extensometers should be recorded independently as a check on test quality.

The method of assembly to the test specimen should ensure the alignment of the extensometer system and the accurate definition of gauge length.

The cost and weight should be low.

3 DESIGN FEATURES

The current area of interest for Structures Department lies mainly in aircraft materials used at temperatures up to 250°C and test times up to 30000 hours. An important aspect of the research programme is the measurement and analysis of creep recovery and the small magnitudes involved make it essential to employ a high sensitivity instrument with minimum hysteresis effects.

3.1 Attachment

A gauge length of 4.5 inches was selected as the largest possible using a specimen to B.N.F. design (Fig.1).

The attachment to the specimen is by means of conical ended pinch screws mounted in laterally flexible ears (Fig.2) to ensure a relatively constant attachment load even with high creep deformation. It is recognised that this type of attachment will produce local stress concentrations in the specimen but it is considered that the effects produced are small in normal creep testing relative to the large gauge length being employed. Rupture life may well be seriously affected by this type of attachment particularly in notch sensitive materials and if operation in this region is required a redesigned specimen incorporating attachment ears will be necessary.

3.2 Transmission

Geometrical effects produced within the extensometer assembly from small lateral displacements or rotations can occur in conventional creep extensometers because the geometry is not fixed relative to the specimen but to a point outside the oven either against the pull rod or through a cage around the pull rod to the opposite extensometer. It therefore follows that any change in alignment between the specimen and this point will produce rotation of one extensometer leg relative to the other. This rotation about centres differing by the gauge length results in a relative movement of the legs at the sensing element and therefore an error in strain indication.

An analysis of this effect is contained in Appendix A and graphs Figs.3 and 4 show the extensometer error as a function of lateral displacement for various extensometers.

During loading lateral displacement is produced by the alignment of an initially slack system together with an additional elastic component resulting from non-axiality generally throughout the test assembly. In the subsequent creep phase lateral displacement will depend on the amount of non-axiality present in both specimen and test assembly in conjunction with the frictional characteristics and location of the universal joints. The forces exerted by oven packing on the extensometer legs will also have an effect on lateral displacement and the consequences of accidental disturbance on the above factors cannot be neglected.

The possibility of strain errors arising from lateral displacements or rotations of the magnitude indicated in Appendix A and graphs Figs.3 and 4 was viewed very seriously. It was required to read left-hand and right-hand extensometers separately to the highest possible accuracy as an indication of test quality and it was apparent that this would be impossible with conventional types of extensometers. Even with extensometer readings averaged it seemed possible that errors exceeding the Class A requirements[3] for repeatability at low strain values could occur.

Considerable thought and effort was directed at this problem and it became apparent that to prevent relative rotations some form of parallel motion system linking the upper and lower extensometer legs would be necessary. It should be noted that certain types of room temperature extensometers for example the Lamb are inherently parallel motion systems. The need for precisely defined parallel motion also seems to have been recognised in instruments used in the calibration of extensometers and it was decided to extend this feature to the creep extensometers being designed.

The choice for the parallel motion system seemed to lie between rollers and leaf springs. The elimination of friction, the high lateral restraint provided, the ease of manufacture and attachment, and the absence of roller clamping loads in the extensometer legs made the selection of leaf springs desirable.

The springs were designed to give a total rate in the direction of measurement of 2 lb/in and a deflection of 0.3 inch at a stress of 20000 lb/in^2. The temperature of operation is restricted to below 250°C and the material selected was 0.006 inch thick spring steel. The form of the springs and attachments are shown in Fig.5.

The material selected for extensometer ears and legs was 16 and 20 swg stainless steel to specification S 520. The 20 swg material was folded to form channel sections $\frac{3}{8}$ in × $\frac{3}{8}$ in and $\frac{5}{8}$ in × $\frac{1}{2}$ inch for upper and lower legs respectively. This arrangement allows one leg to nest inside the other and satisfies the requirements for low weight and high stiffness (Fig.2).

The attachment ears were spot welded to the legs and complete leg, ear assemblies were stress relieved for 1000 hours at 250°C before use.

Two pins passing through jig drilled holes in both legs define the gauge length and locate the extensometer on an assembly jig for attachment to the specimen.

3.3 Sensing element

Having transmitted the strain at the specimen through a friction free parallel motion system to a position outside the heating oven a suitable sensing element was the next design problem. It was considered that the basic simplicity and accuracy inherent in the optical lever make it the most suitable as a basic system of measurement and as a standard against which the performance of other transducers can be compared.

The requirements of linearity and freedom from frequent resetting indicated the use of a roller rather than a rhomb to convert linear to angular motion and these factors coupled with the commercial availability of high accuracy rollers led to their adoption.

A $\frac{1}{8}$ inch diameter roller and a mirror to scale distance of 160 cm were selected. The reading accuracy is considered to be ±0.02 cm giving a theoretical accuracy of $\pm 7.8 \times 10^{-6}$ in deflection from the formula,

$$\text{change in specimen gauge length} = \frac{\text{change in scale reading} \times \text{roller diameter}}{2 \times \text{scale distance}}$$

This is equivalent to a strain of 1.7×10^{-6} inch/inch over the 4.5 inch gauge length. The scale length of 160 cm was selected to allow a maximum strain of 1% to be measured without resetting plus an allowance of 0.3% for differential expansion effects during heating to test temperature.

The sensing roller could not be mounted directly between the two extensometer legs since their relationship is defined by the paralled motion leaf springs. The arrangement adopted is shown in Fig.6 and consists of two roller plates one directly mounted to the upper leg, the other being attached to the lower leg by means of a flexible strut. Two rollers are used, the lower performing the function of measurement and the upper serving as an idler only.

The two plates are attracted together by a small magnet mounted in one of them which exerts sufficient force to hold the rollers in position without slip taking place. The roller plates are milled away locally to provide lands on which the rollers run thus providing a determinate clamping system (Fig.6).

The extensometer is completed by the provision of the mirror system. Two optically-worked face-silvered mirrors are used on each extensometer, one attached to the measuring roller and the other to the lower leg to provide the reference datum required. Adjusters are incorporated for the alignment of the optical lever system.

3.4 Miscellaneous

Since the only connections between the upper and lower extensometer legs are two leaf springs and two rollers, friction is reduced to a very low value. The extensometer becomes one self supporting unit connected at the specimen through the attachment screws only and isolated from any contact with the remainder of the test assembly or its opposite number thus eliminating any possibility of interactions taking place. The difficulties usually experienced in the fitting of creep extensometers consisting of several unconnected components are also overcome.

The weight of the extensometry is an important factor and the low total weight of 0.85 lb per unit is largely attributable to the method of leg and ear construction.

4 TEST PROGRAMME

In all creep testing confidence in equipment and techniques arises from the accumulation of test results over an extended period of time. It was considered that extensive development testing of the extensometer and other new items would involve an unacceptable time penalty if carried out in isolation. It was therefore decided to arrange the current research programme[2] so that the degree of repeatability could be assessed at an early stage.

The programme is intended to provide comprehensive creep data on a single material over a wide range of conditions. It includes an investigation into anelastic recovery and the effects of time at temperature to study the significance and interactions of the processes involved.

5 DETAILS OF TEST PROCEDURE

The specimens were all cut in a longitudinal direction from a single sheet of 16 swg clad aluminium alloy sheet to specification DTD 5070A (Appendix B). They conform to BNF design with a 4½ inch gauge length ½ inch wide (Fig.1). Previous experience had shown that the specimen as machined was slightly curved and to eliminate the resulting bending effects specimen edges were ground straight to ±0.00015 inch.

Tests were conducted in eight 2 ton capacity creep testing machines manufactured by Mand Precision Engineering Co. to R.A.E. specification and were located in a temperature controlled laboratory. The machines were fitted with 5 inch internal diameter ovens, 24 inches long. The heating element was divided into three separate zones. An AEI Type RT3R temperature controller was used and the output was fed to the three oven zones through three variacs for temperature gradient control. Loading was by deadweight through a 10:1 overhead lever beam and was applied by a variable speed electric screw jack. The load axis was adjusted to be vertical and the lever beam multiplying ratio was adjusted to be within ±¼% at the load level subsequently used.

The weight of components attached below the gauge length produced a standing stress in the region of 0.18 kg/mm^2 (250 lb/in^2) and this stress was increased to 0.28 kg/mm^2 (400 lb/in^2) to standardise initial conditions by the adjustment of the machine balancing system.

The specimens were aligned in the testing machines using adjustable shackles and measuring bars to insure coincidence with the load axis in both planes to within ±0.0003 inch (Fig.7).

Two extensometers were used one attached to each edge of the specimen using a simple jig to locate them and set the gauge length (Fig.8).

Temperatures were measured by three miniature platinum resistance thermometers distributed equally along the gauge length (Fig.9). All thermometers were calibrated against three master thermometers at the temperature to be subsequently used to a laboratory accuracy of ±0.1°C.

Young's modulus was determined at laboratory temperature, 21°C, in order to check the function and quality of the test assembly. The maximum stress level was restricted to 5.62 kg/mm^2 (8000 lb/in^2) to avoid any possibility of cold work occurring in core or cladding. Two modulus runs were carried out on each specimen, the first before and the second after the oven was positioned and packed. The difference between the two extensometer deflections at maximum load expressed as a percentage of the mean is termed the side to side and was generally within 2½%. Modulus value generally varied by ±2% of their mean. In future any test assemblies exceeding the above tolerances will be rejected. Fig.9 shows the complete test assembly and Fig.10 is a general view showing a testing machine and its associated illuminated scales unit.

The specimen was raised to within 5°C of test temperature in one hour from starting to heat. The test requirement of ±0.2°C at all three measuring positions was then achieved by suitable adjustments to the temperature controller and oven zone variacs during the remainder of the day. The specimen was maintained within the temperature tolerance of ±0.2°C for the duration of the test.

The load required was calculated on initial specimen area making due allowance for the standing stress of 0.28 kg/mm^2 (400 lb/in^2) and was applied 24 hours after the start of the heat up period in one smooth increment taking approximately 15 seconds.

6 RESULTS

The current research programme has now been running for eighteen months and a total time of 50000 hours has been accumulated in about thirty separate tests. A considerable amount of data is therefore available to assess extensometer performance and is presented under the following headings.

6.1 *Incremental loadings and determination of Young's modulus*

One set of readings obtained during a typical incremental loading check is given (Table 1) and is shown graphically (Fig.11). The deviations of the left-hand, right-hand and mean extensometer scale readings from a straight line through the origin and passing through the mean value at maximum load are shown plotted against load (Fig.12).

It can be seen that the deviations are consistent with a datum change in the first increment. This is a typical feature and is attributed to the alighment under loading of an imperfectly balanced test assembly. The scatter about the best straight line through the deviations of the mean readings does not exceed 0.01 cm scale reading, equivalent to a strain of 0.00009%.

The values of Young's modulus derived from the final incremental loading before heating to test temperature for all tests to date are shown in Table 2 together with the mean and standard deviation. The degree of repeatability achieved from test to test is typical for careful tensile testing and it is gratifying that this standard has been achieved with creep extensometers.

6.2 Repeatability of creep data

Ten creep tests have now been carried out on as-received material at the nominally identical conditions of 17.3 kg/mm^2 (11 ton/in^2) at 180^{o}C for a minimum period under load of 96 hours and at least one of these tests has been completed in each of the eight machines currently being used. The measured values of total strain at various times during this loading period are summarized in Table 3 together with the mean values and standard deviations. It will be seen that the standard deviation is approximately 0.0016% up to 25 hours rising thereafter to 0.0026% at 96 hours. The total strain, elastic plus creep, has been plotted against time for all ten tests on Fig.13.

A further three tests in two testing machines have been completed at the lower stress of 11.0 kg/mm^2 (7 ton/in^2) all other conditions remaining constant. These results are presented in Table 4 and on Fig.14. Comparison reveals a similar repeatability to that obtained at the higher stress level.

6.3 Repeatability of recovery data

Five of the tests at 17.3 kg/mm^2 (11 ton/in^2) referred to in the previous section were unloaded after 96 hours on load. The values of total strain recovered at various times from unloading are summarized in Table 5 together with mean values and standard deviations. The standard deviation is approximately constant at 0.0007% up to 72 hours. The recovery data is also shown in graphical form on Fig.15.

7 DISCUSSION

A creep testing technique is the sum of many individual aspects; specimen variability, stability and accuracy of both specimen and laboratory temperatures, axiality and accuracy of loading and the measurement of strain, temperature and time are all factors which influence the results. Test-to-test variation in any of these will prejudice the data obtained.

The standard deviations obtained from ten constant load creep tests carried out at 17.3 kg/mm^2 (11 ton/in^2) at 180°C rises from 0.0016% at zero time to 0.0026% after 96 hours. The mean total strain values at these times are 0.2502% and 0.5460% respectively. A small number of tests carried out at 11.0 kg/mm^2 (7 ton/in^2) show similar deviations. Recovery at 180°C and incremental loading checks at room temperature resulted in standard deviations of 0.0007% strain in both cases irrespective of the range of movement.

Part of the analysis involves the fitting of a polynomial to the data points for the evaluation of strain rates. The appropriate polynomial can therefore be used to assess the scatter of the data points in individual tests and standard deviations of 0.0002% strain are found to be typical.

The high degree of repeatability and low scatter achieved in the above results is considered highly satisfactory and provides assurance that individual aspects of the testing technique are being controlled in a consistent manner.

It is considered that the most significant errors arising from the extensometry are those associated with the attachment to the specimen. These are local effects however and are probably small compared with the bulk creep strain occurring within the large gauge length of 4.5 inch. Certainly the loads and moments being imposed are no greater than those associated with heavier conventional instruments.

In their use so far the extensometers have proved to be free of any significant practical difficulties, the fitting of them to the specimen being particularly easy. The major precaution necessary is a stress free initial assembly of the parallel motion system during manufacture to avoid 'oil-canning' of the leaf springs and the resulting nonlinear spring forces in the direction of measurement. Future work will include the calibration, at room temperature, of all units now in use as a routine operation employing a calibrator to AID, Harefield, design which will shortly become available. Tests to determine the effects of extensometer moments and loads and some minor modification work will be carried out. Some thought is also being given to a lighter, cheaper version using commercially available stainless steel angle section for leg construction and to the use of displacement transducers.

8 CONCLUSIONS

The results obtained from the current research programme demonstrates that high quality repeatable creep data is possible using the techniques developed.

The extensometer has proved to be sensitive, consistent, reliable and easy to use. The transmission of specimen strain by a leaf spring parallel motion system to a sensing element employing magnetically loaded measuring rollers reduces effects leading to errors in strain indication and is considered to offer significant advantages over conventional instruments.

Appendix A

ANALYSIS OF LATERAL MOVEMENT ERRORS

Fig.16 shows a conventional extensometer subjected to a lateral movement of the roller centre relative to a line joining the two attachment points.

The roller centre moves along the plane of each leg from the initial positions E_1 and E_2 coincident in the undeflected condition by a distance δ to position E.

It can be shown, considering triangles ACE, BDE, AEF and BEF that

$$e_1^2 = e^2 + (d + \delta)^2 - \left[\frac{(\ell - \delta)^2 - (d + \delta)^2 - a^2}{2a}\right]^2$$

where a = gauge length AB

d = initial lower leg length DE_1

ℓ = initial upper leg length CE_2

e = initial roller offset BD, AC

e_1 = deflected roller offset FE

δ = roller movement along extensometer legs.

Let x = lateral displacement measured at roller centre.

Then $x = e_1 - e = \sqrt{\left\{e^2 + (d + \delta)^2 - \left[\frac{(\ell - \delta)^2 - (d + \delta)^2 - a^2}{2a}\right]^2\right\}} - e$.

Which reduces to $x = \sqrt{\left\{e^2 + \frac{4\, d\ell\, \delta\, (a - \delta)}{a^2}\right\}} - e$

$$4\, d\ell\, \delta^2 - 4\, ad\ell\, \delta + a^2\, (x^2 + 2xe) = 0 \quad . \qquad (1)$$

Hence
$$\delta = \frac{a}{2} \pm \sqrt{\left\{a^2\, \frac{[d\ell - x(x + 2e)]}{4\, d\ell}\right\}} \quad . \qquad (2)$$

Or if δ^2 terms are considered negligible in equation (1)

$$\delta = \frac{ax\, (x + 2e)}{4\, d\ell} \quad . \qquad (3)$$

Indicated movement at extensometer is 2δ and this can be expressed as strain ε as follows.

$$\varepsilon = \frac{x(x + 2e)}{2d\ell} \quad . \tag{4}$$

This expression is the strain error indicated by one extensometer only.

It would seem reasonable to think in terms of 0.050 inch lateral movement during loading and possibly 0.020 inch during subsequent creep. Fig.3 shows extensometer error as a function of lateral displacement using expression (4) for the Structures Department extensometer without parallel motion system and also for a typical creep extensometer in general use.

The addition of left-hand and right-hand extensometer readings to obtain mean values results in the cancellation of the most significant term, assuming equal and opposite lateral movements, to give

$$\text{Mean } \varepsilon = \frac{x^2}{2d\ell} \quad . \tag{5}$$

Fig.4 shows the mean error calculated from expression (5) for the same geometries. It should be noted that the much lower error is an optimum condition which can only be approached since it depends on the exact cancellation of the most significant term. Any difference in demensions between the two extensometers will influence this. The case of the integrating extensometer where the attachment to sensing element distance differs in left hand and right-hand extensometers is of interest and Fig.4 shows the larger errors to be expected from this arrangement.

The approximate relationships (4) and (5) have been used to derive the above curves, the difference between exact and approximate being 0.03% and 2.5% in the single and mean strain errors respectively at 0.050 inch lateral displacement.

Appendix B

Extract from specification DTD 5070A for clad aluminium alloy sheet.

(a) Chemical composition of core material:-

	Per cent	
Element	Minimum	Maximum
Copper	1.8	2.7
Magnesium	1.2	1.8
Silicon	-	0.25
Iron	0.9	1.4
Manganese	-	0.2
Nickel	0.8	1.4
Zinc	-	0.1
Lead	-	0.05
Tin	-	0.05
Titanium	-	0.2
Aluminium	-	the remainder

(b) Chemical composition of coating:-

	Per cent	
Element	Minimum	Maximum
Zinc	0.8	1.2
Aluminium	-	the remainder

(c) Minimum mechanical properties:-

0.1% proof stress	not less than 20 ton/sq in
Tensile strength	not less than 25 ton/sq in
Elongation	not less than 6%

(d) Heat treatment:-

Solution treatment by heating at 530 $\pm 5^{o}C$.

Quench in water at a temperature not exceeding $40^{o}C$.

Precipitation treatment by heating uniformly at 190 $\pm 5^{o}C$ for 10 to 30 hours.

Table 1

TYPICAL COLD MODULUS TEST:- RE 16

Load W lb	Scale deflections x cm			Linear relationship $x = \frac{7.875}{240} \times W$
	Left-hand extensometer	Right-hand extensometer	Mean	
0	0	0	0	0
20	0.63	0.62	0.63	0.66
40	1.26	1.32	1.29	1.31
60	1.90	1.97	1.94	1.97
80	2.55	2.65	2.60	2.63
100	3.20	3.31	3.26	3.28
120	3.88	3.98	3.93	3.94
140	4.52	4.64	4.58	4.59
160	5.20	5.28	5.24	5.25
180	5.85	5.95	5.90	5.91
200	6.51	6.60	6.56	6.56
220	7.16	7.26	7.21	7.22
240	7.82	7.93	7.875	7.875
200	6.52	6.60	6.56	6.56
160	5.22	5.32	5.27	5.25
120	3.90	3.99	3.95	3.94
80	2.59	2.67	2.63	2.63
40	1.30	1.33	1.32	1.31
20	0.67	0.67	0.67	0.66
0	0	-0.01	0	0

Specimen area = 0.0322 in^2

Extensometer roller diameters = 0.1250 in

Scale distance = 160 cm

Gauge length = 4.5 in

Laboratory temperature = 21°C

$E = 10.87 \times 10^6$ lb/in^2

Side to side = 1.4%

Table 2

COLLECTED VALUES OF YOUNG'S MODULUS

Test No	M/C No	$\frac{E}{10^6}$	Side to side
RE 4	4	11.02	0.4%
7	3	11.26	0.3
8	7	11.26	0.3
9	3	11.14	0.5
10	4	11.04	1.4
11	6	10.94	3.3
12	1	11.07	1.3
13	6	10.91	1.1
14	2	10.98	0.6
15	2	11.00	4.8
16	5	10.87	1.4
17	4	10.96	1.5
18	1	11.10	1.7
19	8	11.22	0.9

Test No	M/C No	$\frac{E}{10^6}$	Side to side
RE 20	4	11.11	1.9%
21	4	11.10	0.4
22	3	10.98	1.5
23	8	11.07	0.8
24	4	11.09	1.3
25	7	11.04	0.5
26	1	10.99	0.1
28	5	10.92	1.0
29	6	10.84	1.2
31	2	11.00	0.9
32	7	11.17	0
33	8	10.88	0.4
35	2	11.01	1.0
36	8	11.04	1.9

Mean value of E = 11.04×10^6 lb/in^2

Standard deviation = 0.11×10^6 lb/in^2

Laboratory temperature = 21 $\pm 1^{\circ}$C

Table 3

CREEP REPEATABILITY:- 17.3 kg/mm^2 (11 ton/in^2) at 180°C

Time hr	Total strain % (elastic + creep)											Standard deviation
	RE 7	RE 8	RE 11	RE 13	RE 14	RE 16	RE 19	RE 21	RE 26	RE 29	Mean	
0	0.2470	0.2496	0.2498	0.2504	0.2530	0.2518	0.2503	0.2486	0.2508	0.2511	0.2502	0.0016
0.1	0.2711	0.2756	0.2747	0.2762	0.2767	0.2763	0.2753	0.2730	0.2756	0.2749	0.2749	0.0016
0.25	0.2803	0.2845	0.2836	0.2849	0.2851	0.2851	0.2841	0.2815	0.2847	0.2828	0.2837	0.0016
1.0	0.2970	0.3018	0.3001	0.3023	0.3021	0.3018	0.3009	0.2988	0.3012	0.3008	0.3007	0.0016
2.6	0.3138	0.3190	0.3164	0.3185	0.3187	0.3180	0.3170	0.3152	0.3186	0.3174	0.3173	0.0016
10	0.3520	0.3565	0.3546	0.3558	0.3564	0.3551	0.3544	0.3527	0.3559	0.3549	0.3548	0.0014
25	0.3979	0.4016	0.3993	0.4012	0.4017	0.3992	0.4004	0.3974	0.4003	0.3999	0.3999	0.0014
96	0.5439	0.5471	0.5457	0.5445	0.5479	0.5449	0.5518	0.5420	0.5446	0.5480	0.5460	0.0026

Table 4

CREEP REPEATABILITY:- 11 kg/mm^2 (7 ton/in^2) at 180°C

Time hr	Total strain % (elastic + creep)			
	RE 15	RE 31	RE 32	Mean
0	0.1548	0.1544	0.1534	0.1542
0.1	0.1618	0.1610	0.1603	0.1610
0.25	0.1650	0.1643	0.1632	0.1642
1.0	0.1719	0.1714	0.1699	0.1711
2.6	0.1787	0.1777	0.1771	0.1778
10	0.1925	0.1927	0.1924	0.1925
25	0.2083	0.2086	0.2076	0.2082
96	0.2457	0.2473	0.2465	0.2465

Table 5

RECOVERY REPEATABILITY:- AFTER 96 hr AT 17.3 kg/mm^2 (11 ton/in^2) AT 180°C

Time hr	Total strain recovered % (elastic + recovery)						Standard deviation
	RE 7	RE 11	RE 13	RE 14	RE 16	Mean	
0	0.2485	0.2491	0.2500	0.2498	0.2516	0.2498	0.0010
0.1	0.2612	0.2622	0.2626	0.2616	0.2632	0.2622	0.0007
0.25	0.2650	0.2659	0.2663	0.2653	0.2673	0.2660	0.0008
1.0	0.2711	0.2721	0.2727	0.2716	0.2732	0.2721	0.0007
2.6	0.2757	0.2767	0.2775	0.2764	0.2777	0.2768	0.0007
10	0.2832	0.2843	0.2850	0.2838	0.2844	0.2841	0.0006
26	0.2889	0.2896	0.2903	0.2892	0.2899	0.2896	0.0005
72	0.2938	0.2949	0.2959	0.2945	0.2953	0.2949	0.0007
312	-	0.3004	0.3032	0.2994	0.3037	0.3017	-
600	-	0.3027	-	0.3016	0.3060	0.3034	-
912	-	0.3041	-	0 -	0.3070	0.3056	-

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2	D. A. Berry R. F. W. Anstee	A preliminary study of the creep and recovery behaviour of DTD 5070A aluminium alloy from the Joint British Committee for stress analysis Conference. Roy. Aero. Soc. (1968)
3	British Standards Institution	Methods of calibration and grading of extensometers for testing of materials BS 3846. London, British Standards Institution (1965)

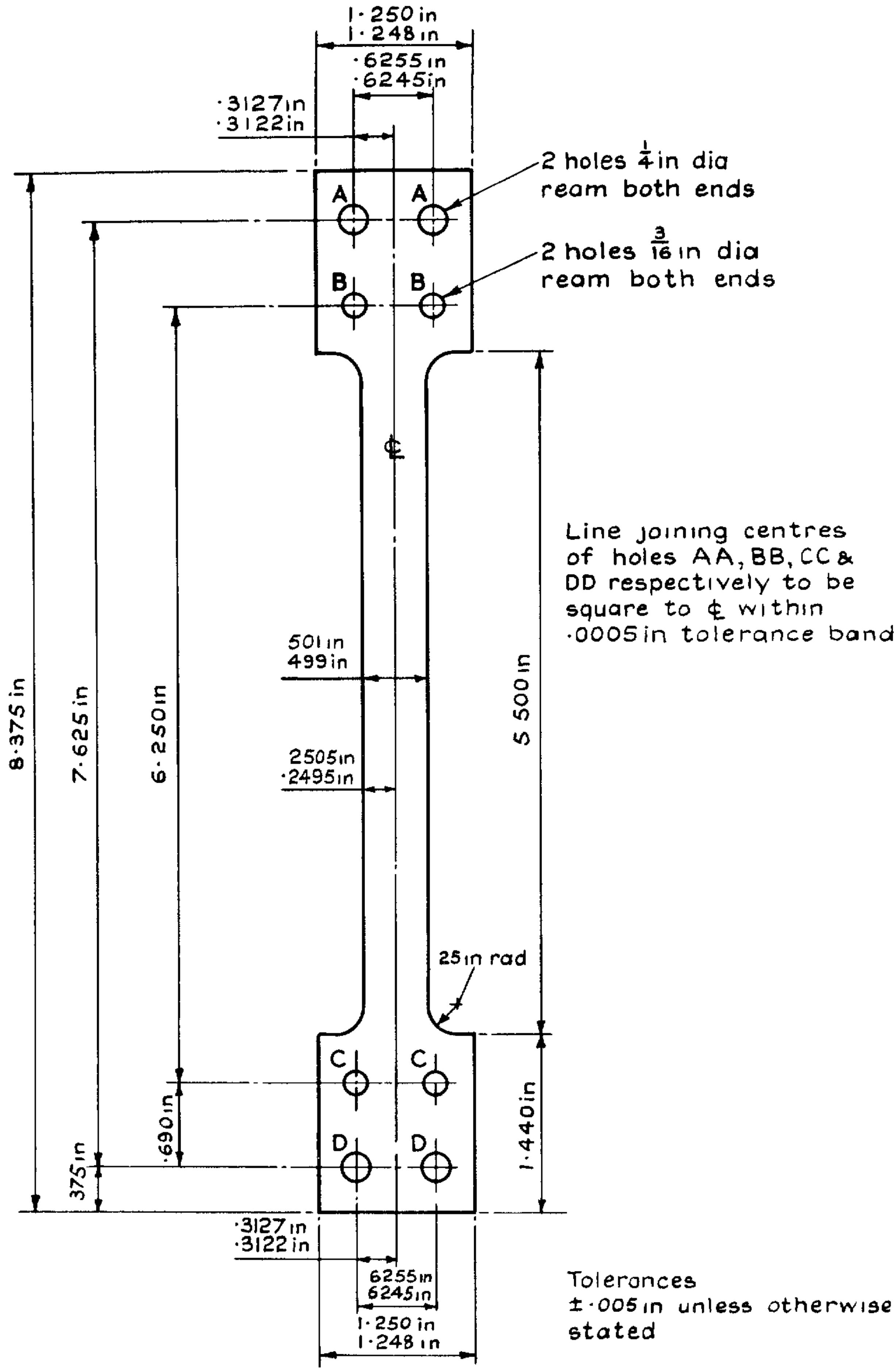


Fig. 1 Sheet test pieces

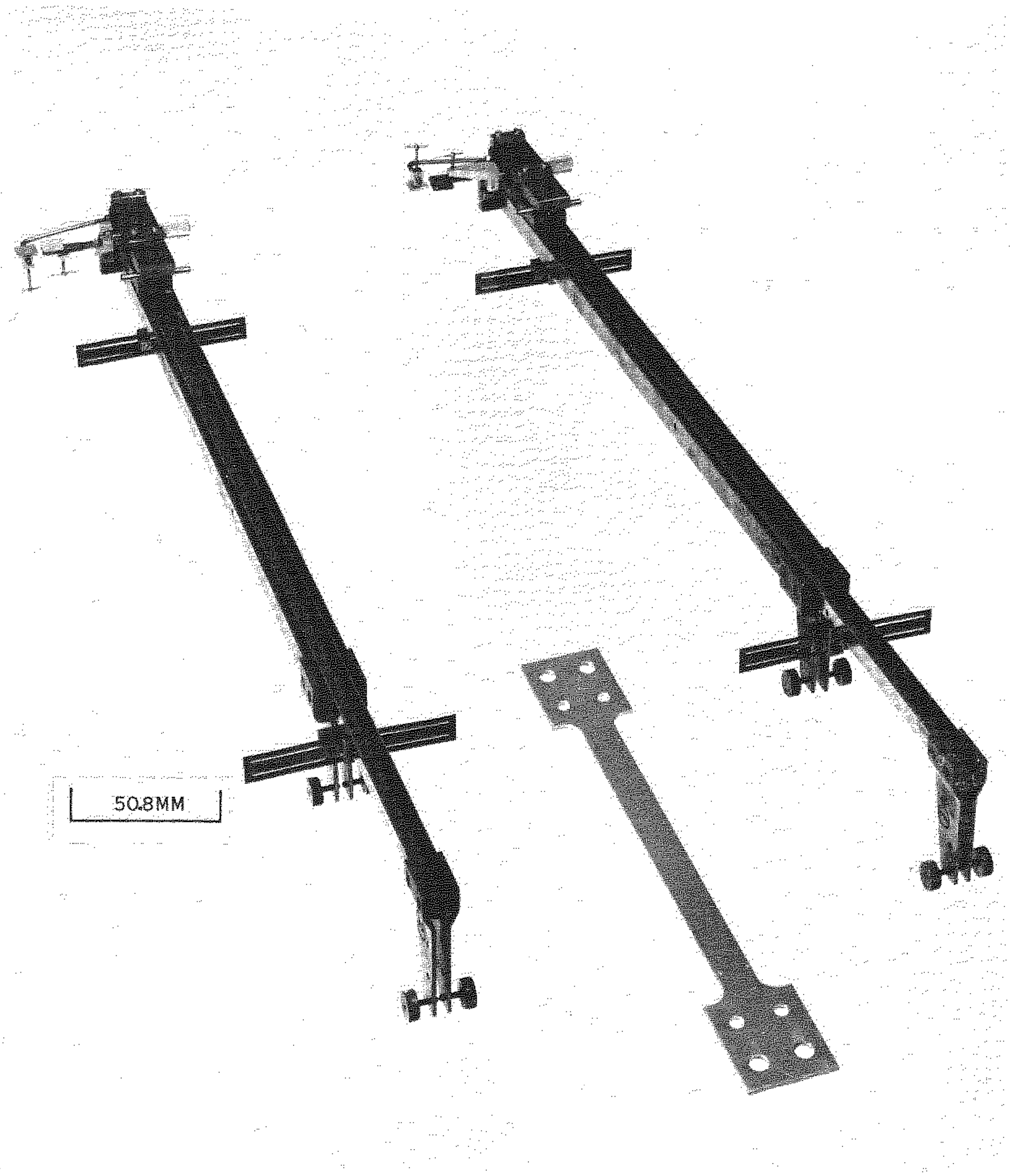
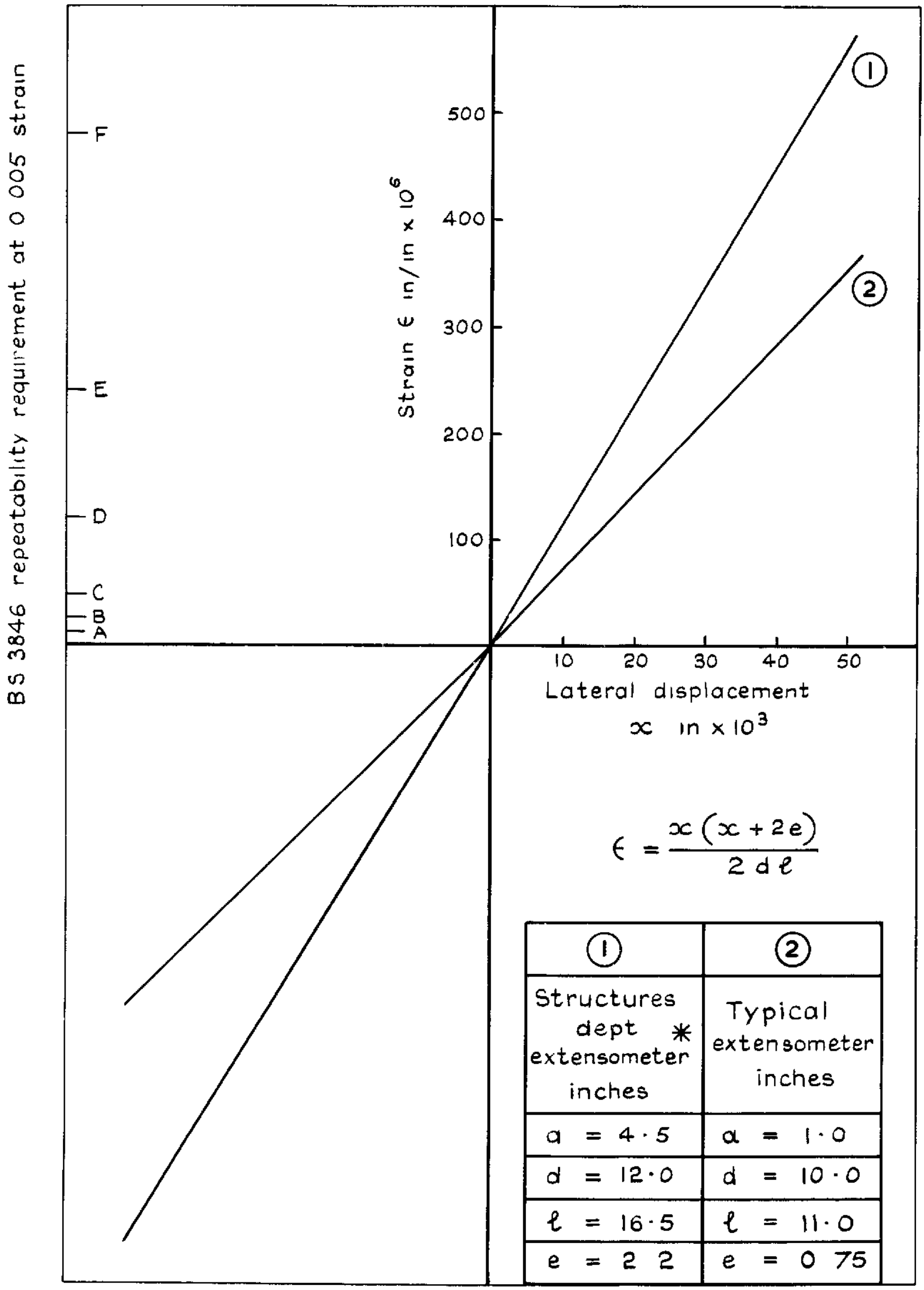
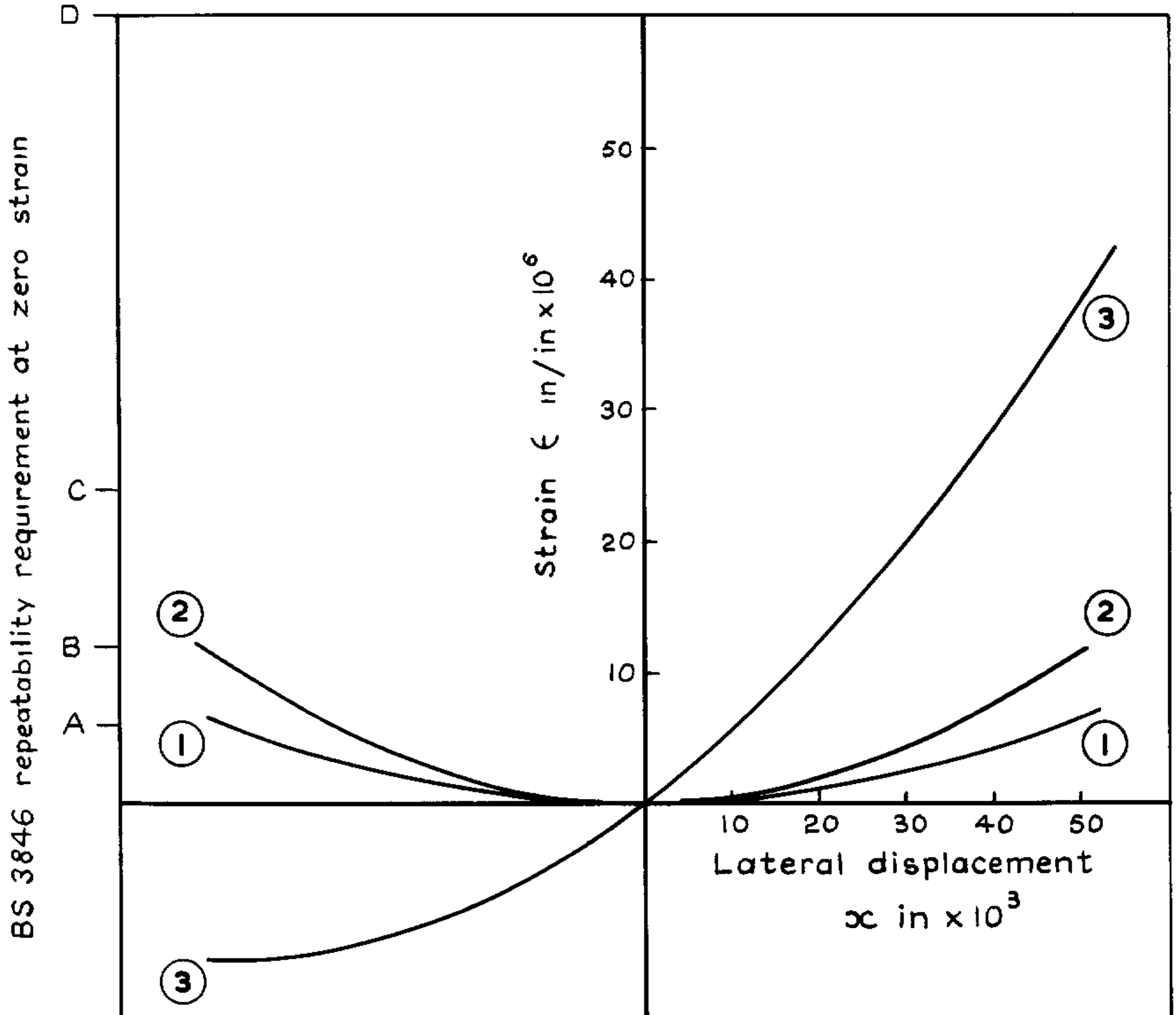


Fig.2. Parallel motion extensometers



* Without parallel motion system

Fig. 3 Strain error against lateral displacement for single extensometers



①	②
Structures dept * extensometer inches	Typical extensometer inches
a = 4·5	a = 1·0
d = 12·0	d = 10·0
ℓ = 16·5	ℓ = 11·0
e = 2·2	e = 0·75

③	
Typical integrating extensometer	
Lh inches	Rh inches
a = 1·0	a = 1·0
d = 9·25	d = 10·75
ℓ = 10·25	ℓ = 11·75
e = 0·75	e = 0·75

* *Without parallel motion system*

Fig. 4 Mean strain error against lateral displacement for double extensometer

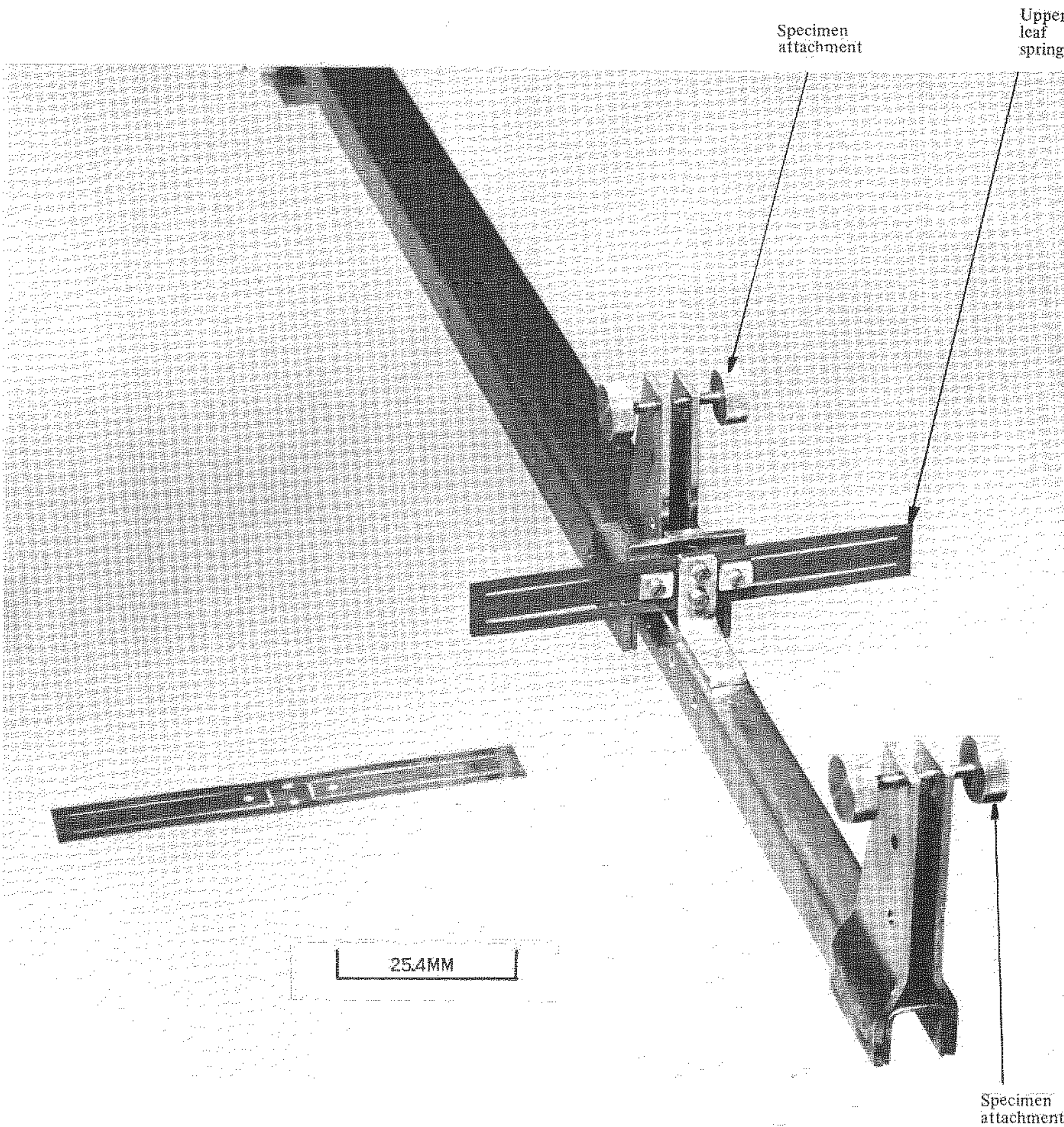


Fig.5. Leaf spring attachment

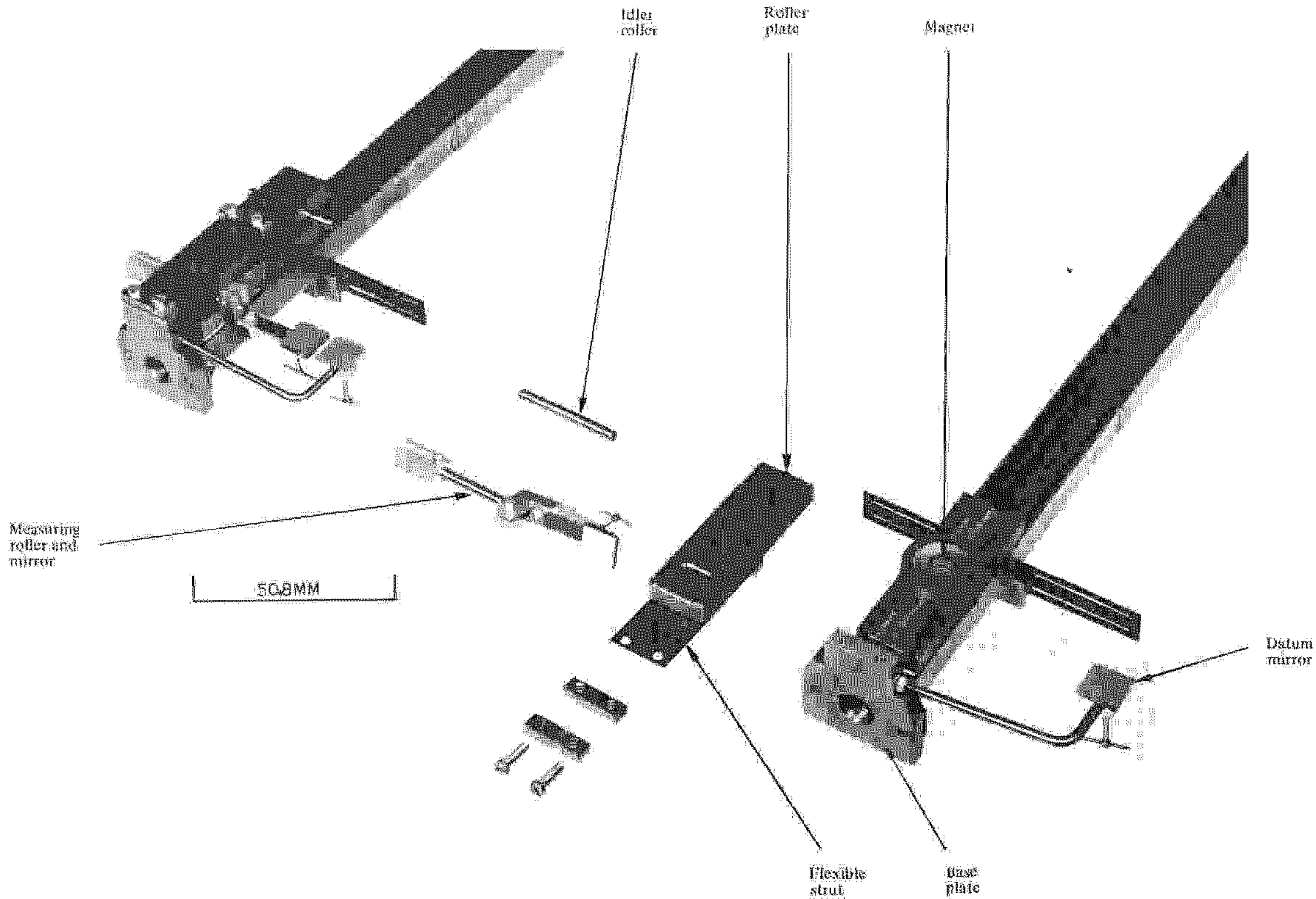


Fig.6. Sensing element

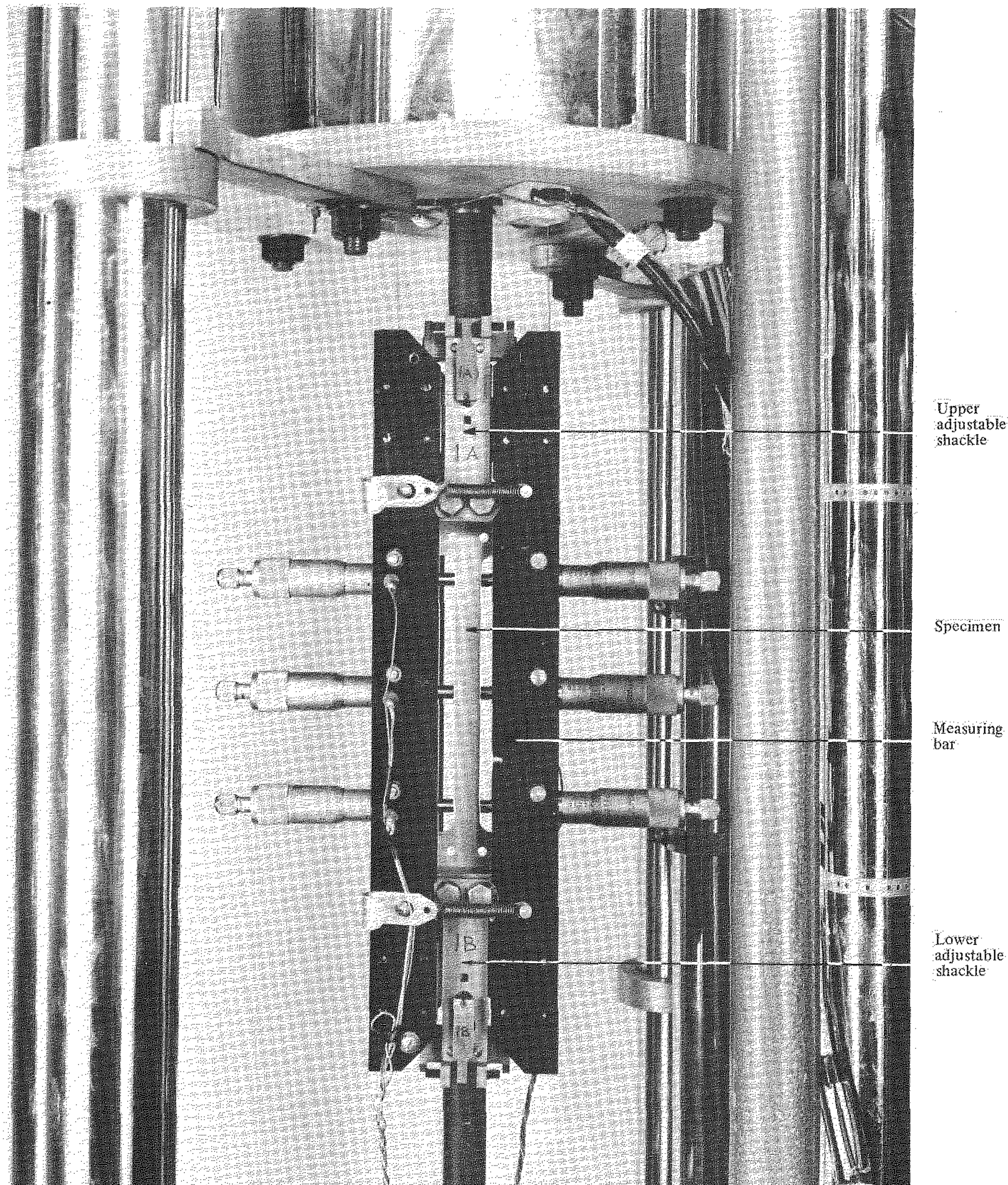


Fig.7. Specimen alignment

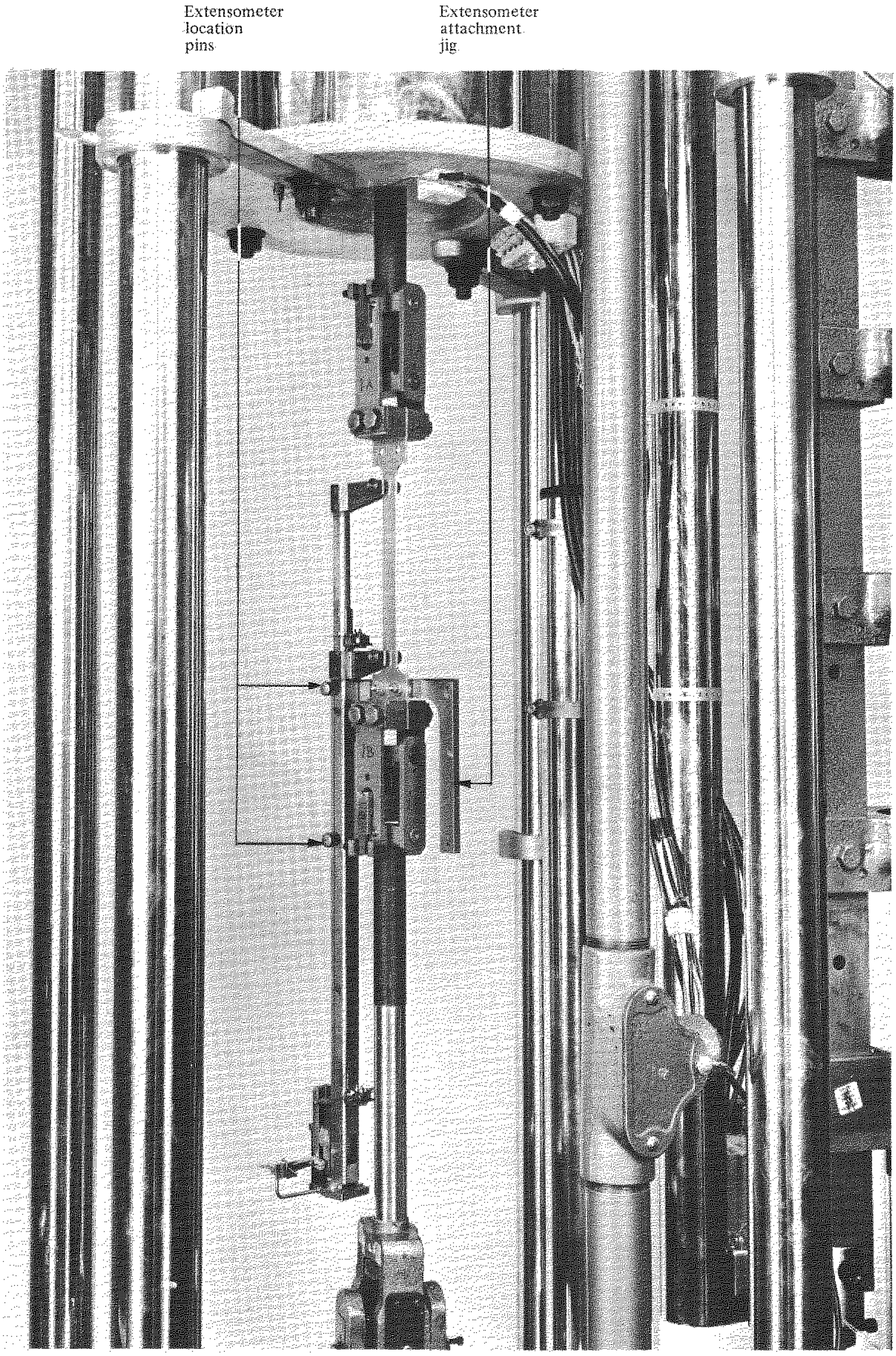


Fig.8. Extensometer attachment jig

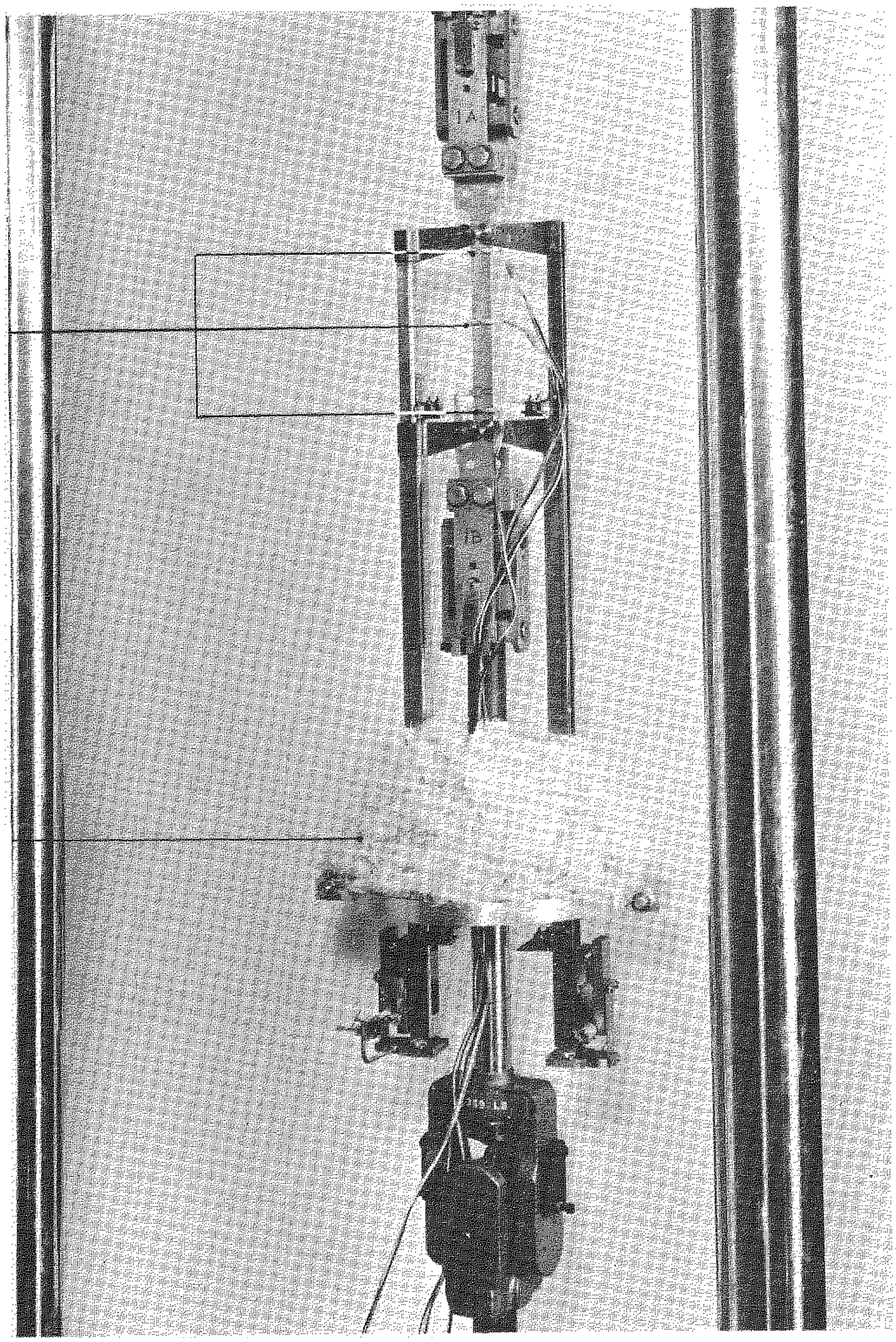


Fig.9. Completed test assembly

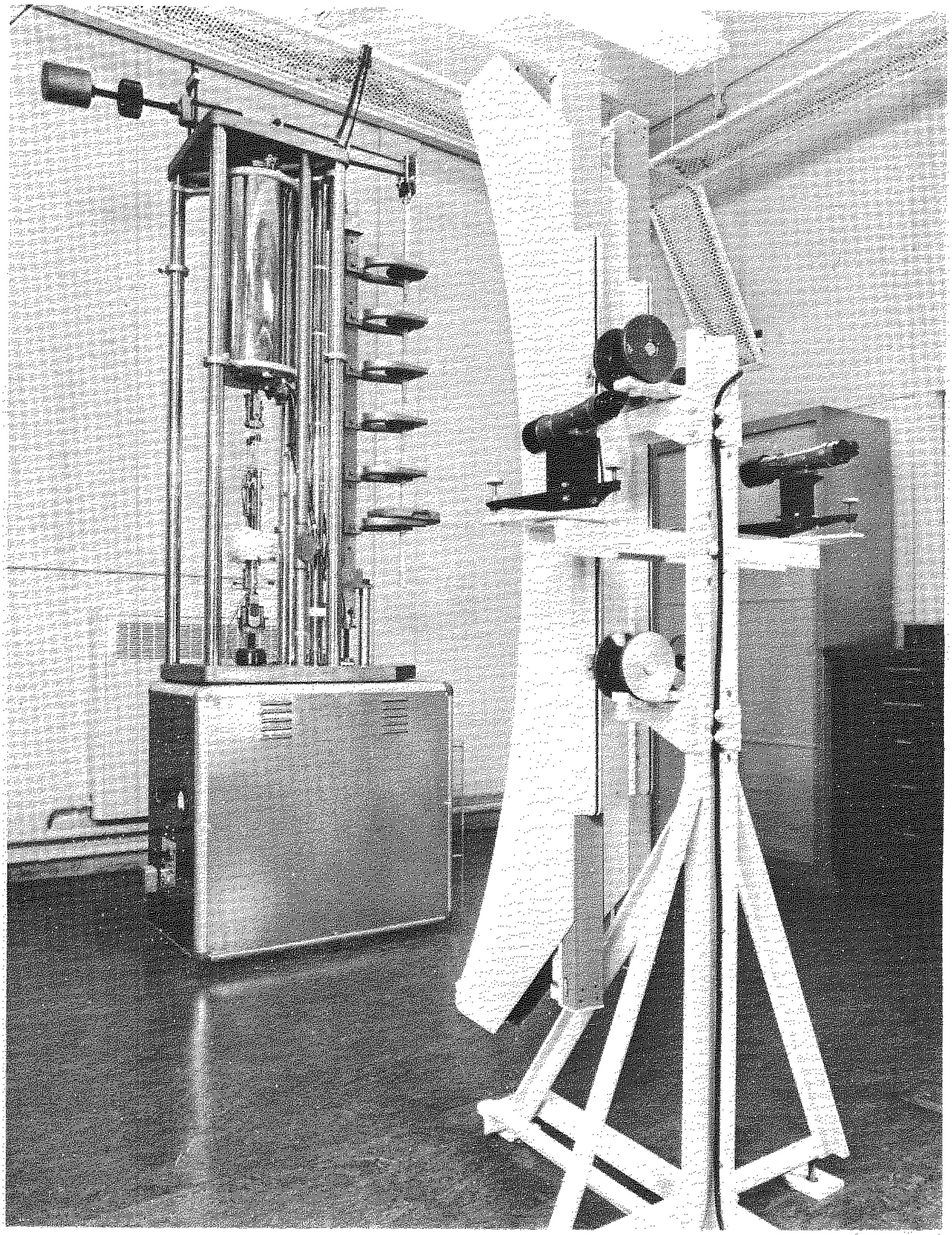


Fig.10. Test assembly, machine and scale unit

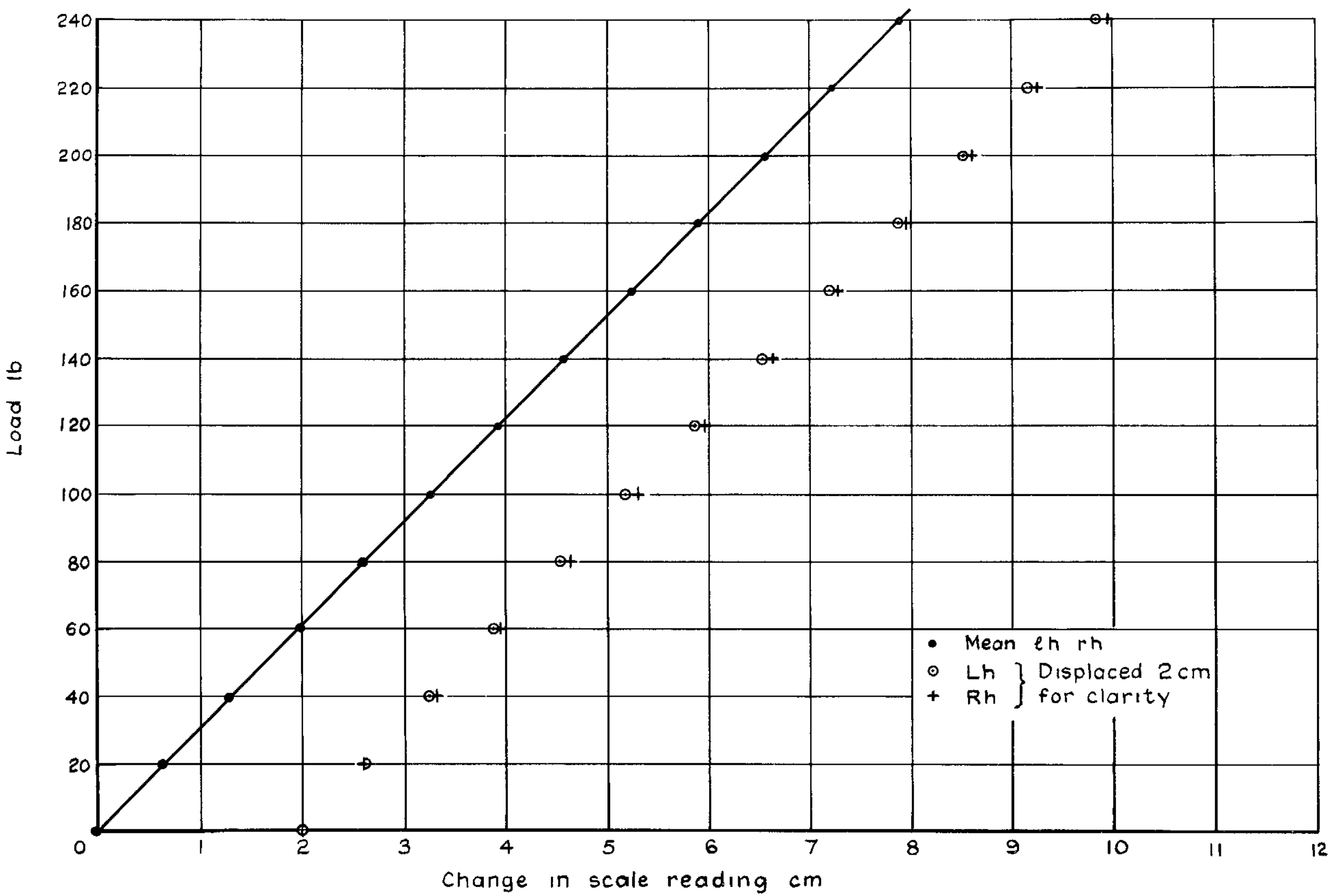


Fig. 11 Typical cold modulus test :- RE 16

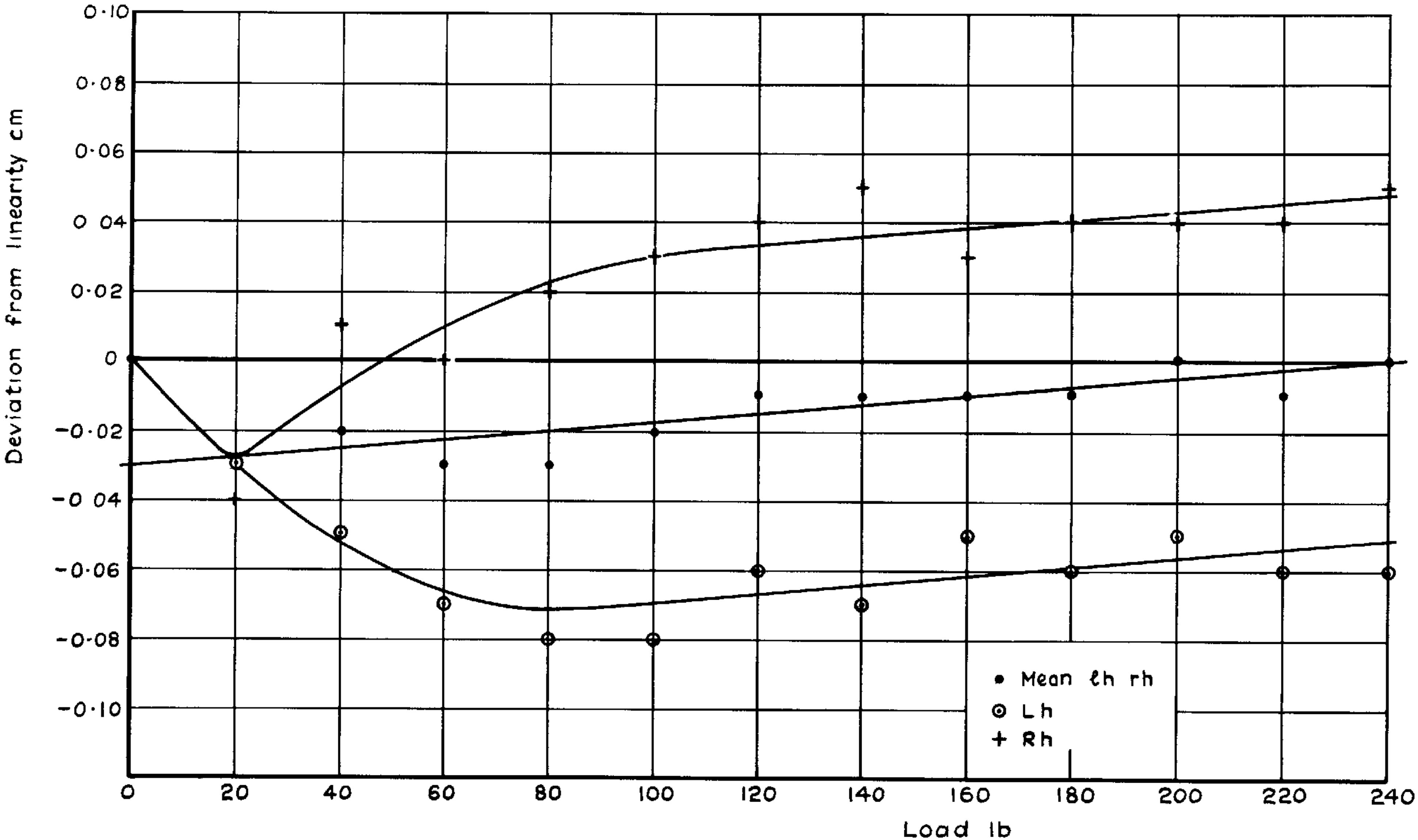


Fig. 12 Typical cold modulus test :— RE 16

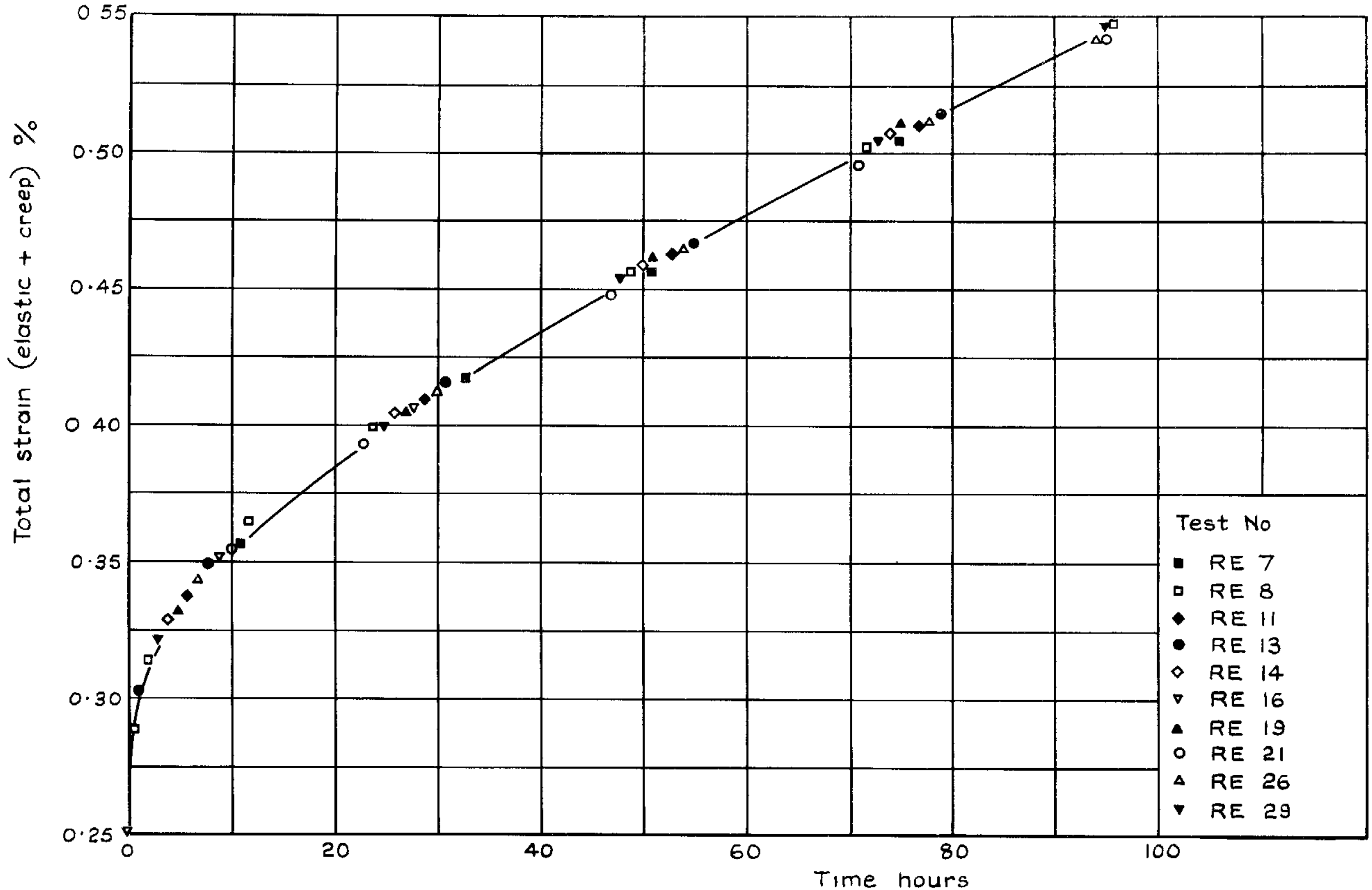


Fig. 13 Repeatability of creep tests :– 17·3 kg/mm^2 (11 ton/in^2) at 180°C

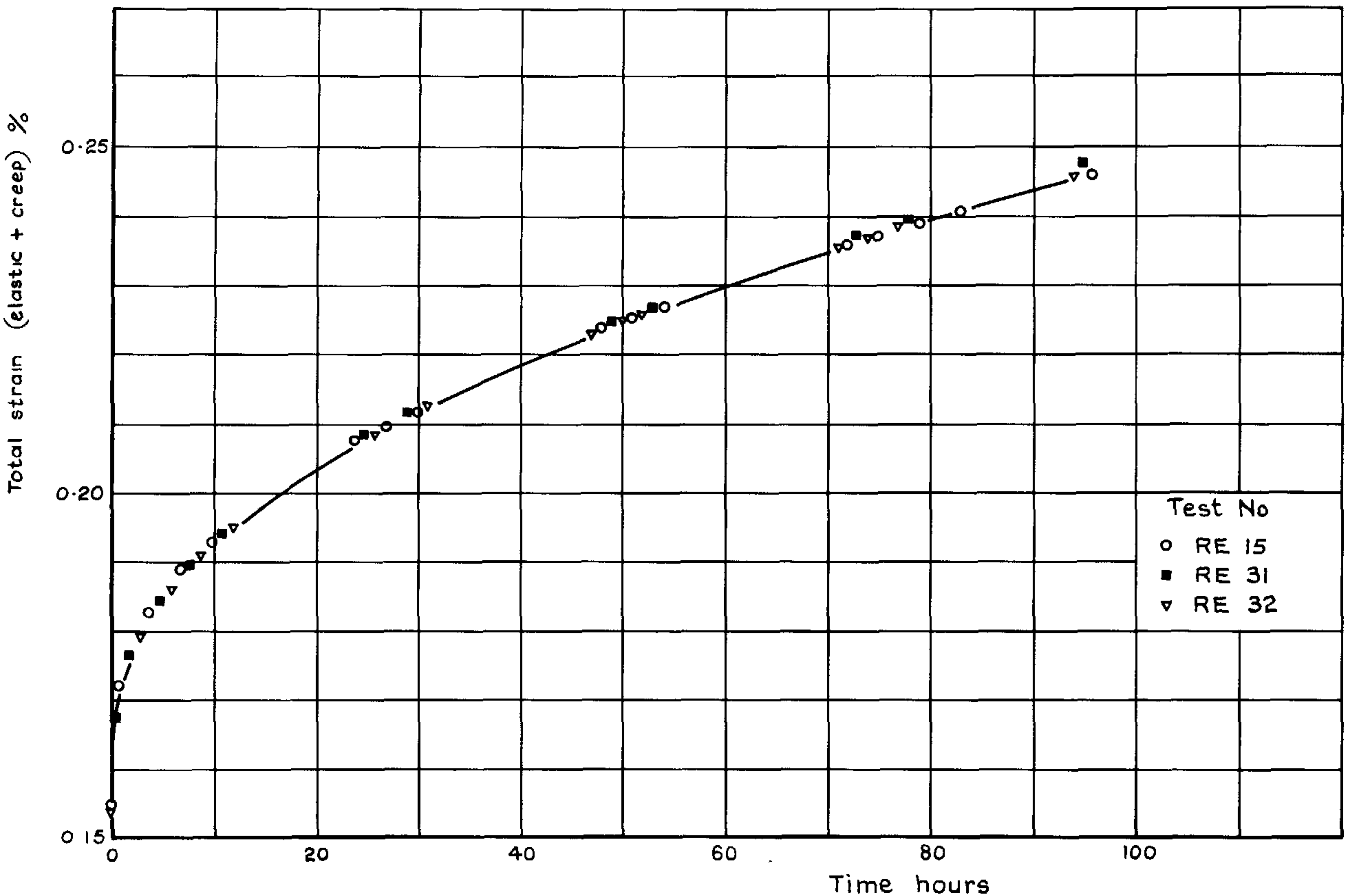


Fig. 14 Repeatability of creep tests:– 11·0 kg/mm² (7 ton/in²) at 180°C

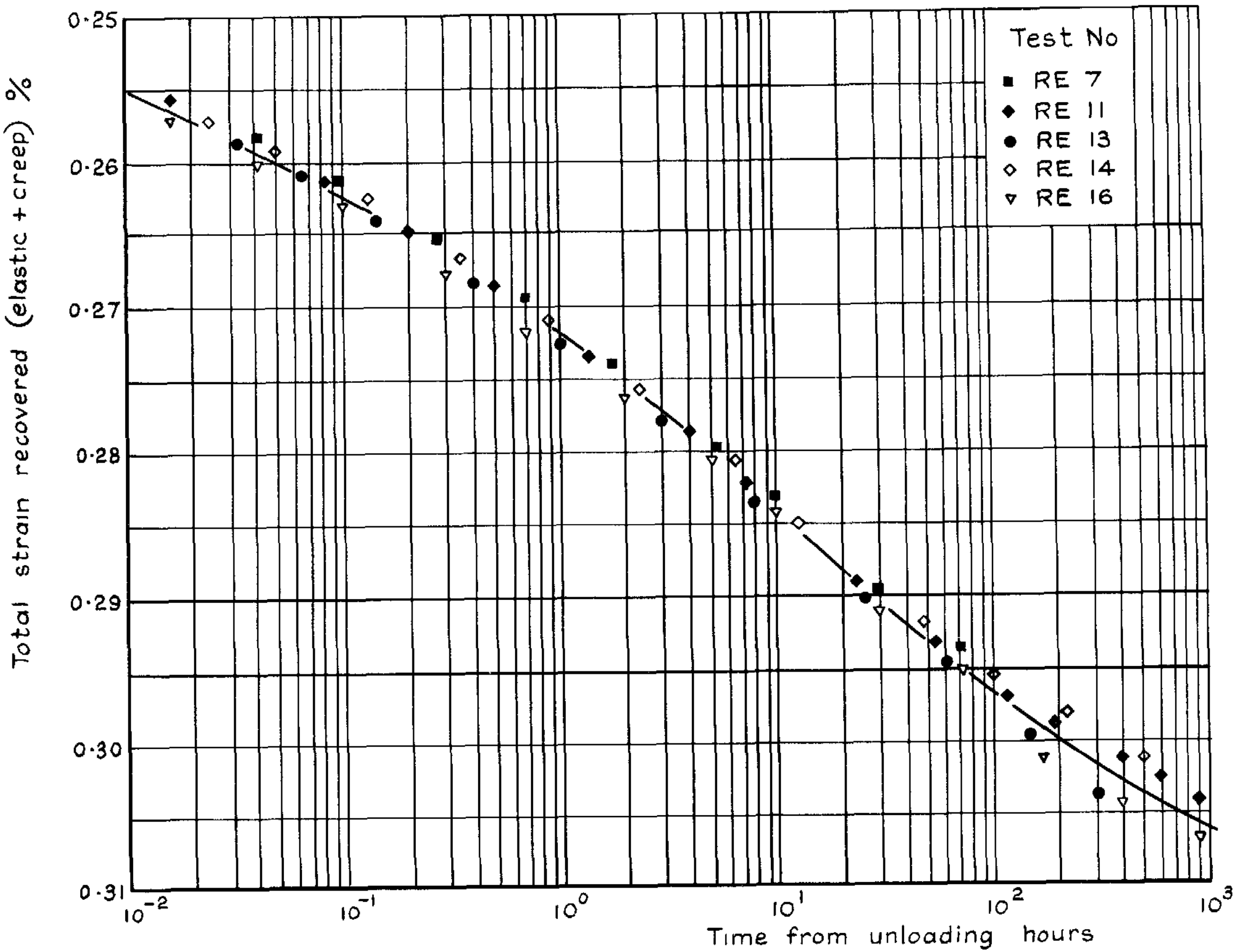
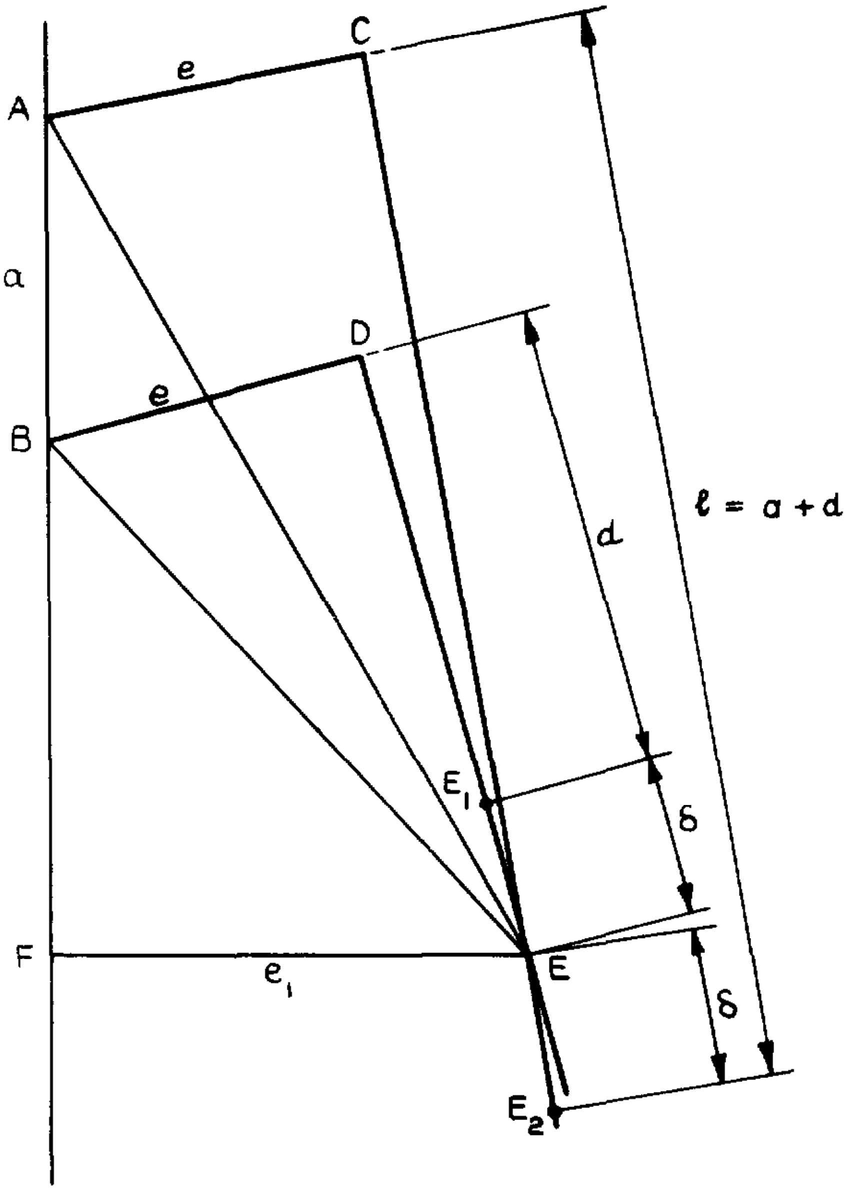


Fig. 15 Recovery repeatability:— after 96 hr at 17·3 kg/mm^2 (11 ton/in^2) at 180°C



a = Gauge length A B

d = Initial lower leg length DE_1

ℓ = Initial upper leg length CE_2

e = Initial roller offset BD, AC

e_1 = Deflected roller offset FE

δ = Roller movement along extensometer leg

Note :- Not to scale, displacements exaggerated for clarity

Fig. 16 Effect of lateral deflection on extensometer geometry

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